Heat Transfer in a Foam Insulated Block

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INTRODUCTION

The heat transfer through a common household building block can lead to significant energy losses. By insulating the block with a foam core, heat losses have the potential to be diminished. To determine the extent to which the loss of heat has been reduced, the calculated effective R value, a measure of thermal resistance, of the foam insulated wall can be compared to the calculated effective R value of a standard, non-insulated wall. A transient thermal analysis using ANSYS, a finite element mathematic modeling program, will indicate the total amount of heat loss through the wall, as well as the effectiveness of the foam as an insulator. It is expected that the foam insulation will decrease the heat loss. Using the results of this study, energy savings over a certain period of time can be found and compared for buildings constructed from these blocks.

Utilization of these building blocks in conventional homes will decrease the amount of heat transferred between the house and its surroundings. Knowing the reduction in heat loss between the foam insulated block and the conventional block will allow for a calculation of energy savings, and thus money saved, over a certain period of time.

OBJECTIVES

Code Verification – Simple Rectangular Block

- One dimensional *steady state* conduction comparison of Heat Diffusion theory and Finite Element Methods (ANSYS)
- One dimensional *transient* conduction comparison of Heat Diffusion theory and Finite Element Methods (ANSYS)

Geometry Specification

- Use Pro Engineer to construct solid model of foam insulated block
- Find all possible permutations of multiple block configurations
- Find symmetry in a wall composed of multiple blocks

ANSYS Analysis – Complex Geometry Block

- Import Pro|E model into ANSYS with thermal properties of both concrete and foam insulation
- Perform three dimensional transient study to find heat flux for a given temperature difference
- Wall surface temperature obtained from air temperature relations for weather data for a specific geographic climate

Comparison of Effective R-values

- Calculate effective R-values for standard walls to find the energy savings of the foam insulated wall.

METHODS

Code Verification – Simple Rectangular Block

While verifying the finite element code (ANSYS), foam was not used in the model to keep the geometry simple, which allowed for an analytical solution to be obtained for the heat diffusion equation. Properties of concrete used for calculations are listed below.

- Thermal Conductivity, k = 1.4 W/m*K
- Density, ρ = 2300 kg/m^3
- Specific Heat, c_p = 880 J/kg*K

For the steady-state solution, the two boundary conditions were chosen as constant surface temperatures on two parallel faces. For the transient solution, the two boundary conditions were again chosen as constant surface temperatures on two parallel faces, and the initial condition was chosen as an initial temperature of the block. The heat diffusion equation used for both the steady-state and transient solutions is

$$\nabla \cdot k \nabla T + \dot{q} = \rho c_p \frac{\partial T}{\partial t}$$

Assumptions made for both steady-state and transient studies included constant thermal conductivity, no internal heat generation, one dimensional heat transfer, and Cartesian coordinates.

The analytical solutions seen below derived from the heat diffusion equation were plotted using MATLAB.

$$\frac{\partial^2 T}{\partial x^2} = 0 \quad \text{(Steady State)} \qquad \frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \quad \text{(Transient)}$$

A selection of data points from the finite element solution (ANSYS) were also plotted and compared to the analytical solution.

Geometry Specification

The foam insulated block was obtained from NRG Insulated Block in order to create a 3D model. The block was constructed in three separate drawings and then assembled to create the final block. The roughness of the foam and concrete surfaces were not modeled, and thus the contact surfaces between the foam and concrete were smooth.

NEXT STEPS

ANSYS Analysis – Complex Geometry Block

The model completed in Pro|E will be used in a transient thermal conduction analysis in ANSYS. The boundary conditions will no longer be constant surface temperatures, but will instead be time varying surface temperatures. The sides of the block that do not experience contact with air will have a perfectly insulated boundary condition due to symmetry in the wall.

Using the solution for the heat flux due to the temperature gradients, the effective R-value can be calculated for the foam insulated wall using the equation

The effective R-value can also be calculated for a normal building block, and the two values compared. Various climates can be analyzed and the amount of energy saved can then be translated into a monetary savings per unit time.

The wall of bricks will be modeled as an underground basement wall and as an above ground wall to evaluate the most effective configuration.

FINDINGS AND EXPECTED RESULTS

Code Verification

Using MATLAB to plot the solution of both the Heat Diffusion equation and the finite element code for steady state conduction resulted in the following plot.

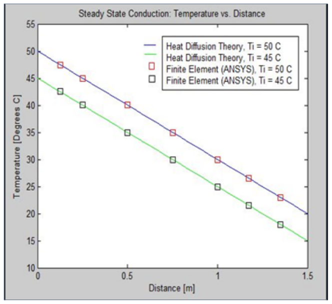

Figure 1: Steady state temperature in the block against time. For steady state conduction, temperature distribution is linear throughout a plane wall.

Using Excel, the trend line of the Finite Element solution was graphed and displayed the same equation that was derived from the heat diffusion equation. The R^2 value of the trend line was 1, indicating a perfect fit.

The transient figures from MATLAB are shown below.

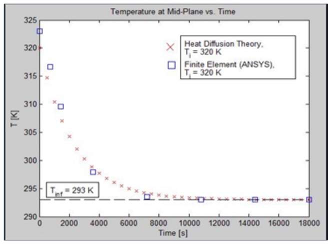

Figure 2: Temperature at mid-plane decreasing with time. The mid-plane temperature is also the maximum temperature at any given time in the block due to the boundary conditions.

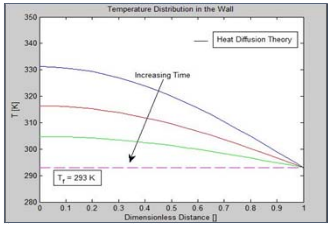

Figure 3: Temperature distribution at various times in the block. The distance in the block has been non-dimensionalized by dividing the x-distance in the block by the entire width of the block.

Various points obtained from ANSYS will be plotted on Figure 3 to further verify the code for the transient case. The x-axis is plotted as a non-dimensional distance in order to obtain a range from zero to one. As time increases, the temperature distributions approach the final steady state value of 293 K.

Figure 4 and 5: Front and back isometric views of the foam insulated building block. Green represents concrete and gray represents foam insulation.

The geometry of the section varies in all three dimensions, so a three dimensional transient study is needed. A refined mesh will be used to focus on sections of increasingly complex geometries such as corners. The roughness of the concrete and foam insulation will be included in the ANSYS code to correctly model the transient.

CONCLUSIONS

There is an excellent agreement between the Heat Diffusion Theory and ANSYS, which verifies the code for the steady state solution. The solution of the transient is also very close. Any errors can be attributed to assumptions in the mathematical model, stated previously in the Methods section.

Obtaining a 3D transient solution for the complex geometry of the foam insulated block is feasible. The economic impact of the block can be assessed with confidence, and a comparison between a standard wall and the foam insulated wall can be conducted. The effect of various climates on heat loss through the walls can also be analyzed.

The amount of energy savings compared to the increase/decrease in cost of construction will dictate the efficacy of this new technology.

REFERENCES

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